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Disorder dependence electron phonon scattering rate of $V_{82}Pd_{18-x}Fe_x$ alloys at low temperature

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ABSTRACT

We have systematically investigated the disorder dependence electron phonon scattering rate in three dimensional disordered $V_{82}Pd_{18-x}Fe_x$ alloys. A minimum in temperature dependence resistivity curve has been observed at low temperature $T = T_m$. In the temperature range $5\ K \leq T \leq T_m$ the resistivity correction follows $\rho_o^{5/2} T^{1/2}$ law. The dephasing scattering time has been calculated from analysis of magnetoresistivity by weak localization theory. The electron dephasing time is dominated by electron–phonon scattering and follows anomalous temperature (T) and disorder (ρ_0) dependence behaviour like $\tau_{\text{e-ph}}^{-1} \propto T^2/\rho_0$, where ρ_0 is the impurity resistivity. The magnitude of the saturated dephasing scattering time (τ_0) at zero temperature decreases with increasing disorder of the samples. Such anomalous behaviour of dephasing scattering rate is still unresolved.

1. Introduction

The dephasing scattering time (τ_ϕ) in an electron wave function has a great importance to study the electron transport in disordered and lower dimensional materials because it sets a scale at which the quantum behaviour transforms to classical behaviour [1,2]. The study of electron dephasing is correlated with some quantum phenomena like conductance fluctuation, weak electron localization, the Aharonov–Bohm effect, etc. [3–7]. Out of these interference phenomena, the weak electron localization is the prominent coherence interference effect, in which the coherency has been destroyed by application of magnetic field. Hence the time reversal symmetry has been broken by application of magnetic field and an anomalous magnetoresistance has been observed in disordered conductors at lower temperature. From the analysis of the magnetoresistance data by using weak electron localization (WEL) theory, the different electron dephasing scattering times have been extracted. The different dephasing scattering mechanisms may arise from electron–electron interaction, electron–phonon interaction, spin–orbit scattering and spin–spin scattering in metallic conductors. It is well established that in case of lower dimensional systems inelastic scattering is dominated by electron–electron interaction (EEI) [8–12], whereas it is dominated by electron–phonon interaction in three dimensional disordered systems [13–19]. For order system ($q_{ph} l_e >> 1$, q_{ph} is the phonon wave number, l_e is the electron mean free path), the temperature dependence of electron–phonon scattering rate is well established both theoretically and experimentally [13,14]. But in disorder system ($q_{ph} l_e << 1$) the nature of electron–phonon scattering mechanism is under controversy [19–23]. Theoretically and experimentally many authors [15–24] have studied the electron–phonon scattering mechanism on different disordered systems but they did not able to predict a universal conclusions. Basically the disorder dependence of electron–phonon scattering rate and saturated dephasing scattering rate is under debate. As resistivity at lower temperature (ρ_0) is the measurement of order of disorderness present in the samples, we have prepared some $V_{82}Pd_{18-x}Fe_x$ disordered alloys having different resistivity (ρ_0). To study the disorder dependence of dephasing scattering mechanisms, we made an attempt to calculate the electron–phonon scattering time, spin–orbit scattering time and zero temperature scattering time from the analysis of low temperature magnetoresistance data with the help of weak localization theory. In this paper, we have reported the temperature and disorder dependence of electron–phonon scattering and saturated dephasing scattering rate of disordered $V_{82}Pd_{18-x}Fe_x$ alloys at low temperature $5 \leq T \leq 25$ K.

2. Experimental method

Different three dimensional disordered $V_{82}Pd_{18-x}Fe_x$ alloys ($x = 0, 1, 2, 3, 4$) were prepared by a standard arc melting of suitable amounts of spec-pure V, Pd and Fe. To make the sample homogeneous the melted ingots were anneal at 800 °C for 48 hours. Different Iron concentration was used to introduce compositional

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Table 1
Values of relevant physical parameters for disordered $V_{82}Pd_{18-x}Fe_x$ alloys, ρ_o and ρ (300 K) are the resistivity at 10 K and 300 K respectively, l_e is the mean free path, D is the electron diffusion coefficient, K_F is the Fermi wave vector, T_m is the temperature at which resistivity is minimum, F is a screening factor, τ_{SO}^{-1} is the spin–orbit scattering rate and τ_ϕ^{-1} (10 K) is the dephasing scattering rate at 10 K. τ_0^{-1} is the zero temperature dephasing scattering rate, p is the temperature exponent of electron–phonon scattering rate ($\tau_{e\text{-}ph}^{-1}$) and $A_{e\text{-}ph}$ is the strength of electron–phonon coupling.

Parameters	$V_{82}Pd_{18}Fe_0$	$V_{82}Pd_{17}Fe_1$	$V_{82}Pd_{16}Fe_2$	$V_{82}Pd_{15}Fe_3$	$V_{82}Pd_{14}Fe_4$
ρ_0 (μΩ cm)	101	118	127	139	151
ρ (300 K) (μΩ cm)	110	137	156	177	198
l_e (Å)	2.22	1.90	1.77	1.61	1.49
D (cm^2/s)	3.30	2.82	2.62	2.40	2.21
K_F (Å^{-1})	2.33	2.33	2.33	2.33	2.33
T_m (K)	21	22	23	25	26
F	0.89	0.89	0.89	0.89	0.89
τ_{SO}^{-1} (s^{-1})	3.56×10^{13}	3.15×10^{13}	2.79×10^{13}	2.28×10^{13}	2.09×10^{13}
τ_ϕ^{-1} (s^{-1}) (10 K)	1.35×10^{11}	1.25×10^{11}	1.03×10^{11}	9.01×10^{10}	8.21×10^{10}
τ_0^{-1} (s^{-1})	4.21×10^{10}	3.53×10^{10}	2.29×10^{10}	1.79×10^{10}	1.02×10^{10}
P	2.20	2.18	2.12	2.07	2.05
$A_{e\text{-}ph}$ (s^{-1} K^{-p})	5.89×10^8	5.95×10^8	6.10×10^8	6.39×10^8	6.47×10^8

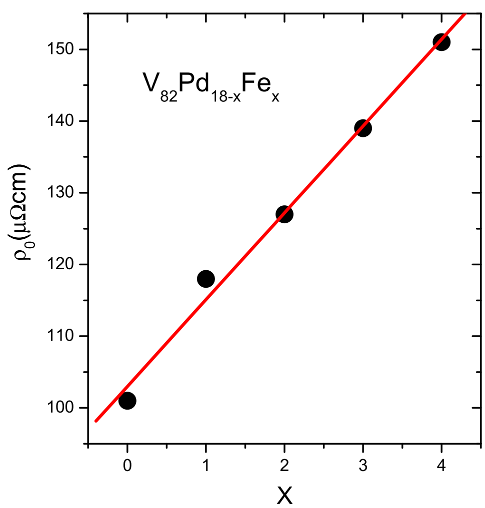

Fig. 1. Impurity resistivity (ρ_0) as a function of iron concentration (x) of different disordered $V_{82}Pd_{18-x}Fe_x$ alloys. The straight line is a guide to the eye.

disorder within the samples. For electrical study the samples were cut into rectangular shape ($0.2 \times 0.2 \times 10$ mm^3) and fine copper wires were spot-welded on to the samples as electrodes. Standard four probe technique was used for resistance and magnetoresistance measurement. The measurement was performed in the temperature range, $5 \le T \le 300$ K by using a closed cycle Helium Cryostat. The temperature was controlled and measured by a lakeshore 335 temperature controller. To avoid the Joule heating current level was kept low. The magnetoresistance was measured at low magnetic field (an electromagnet was used for production of magnetic field) to minimize the electron–electron interaction contribution. Fermi wave vector (K_F) and elastic mean free path 'l_e' of electron have been calculated by using free electron theory [18,25]. The values of the electron diffusion constant D has been found out from the relations $D = \frac{1}{3} v_F l_e$ and $v_F = \frac{\hbar K_F}{m}$, where m is $1.46 m_0$, m_0 is the free electron mass [16]. In the calculation of different parameters, the variation of effective mass m with small change of x has been assumed negligible in the investigated $V_{82}Pd_{18-x}Fe_x$ alloys. The calculated values of the parameters like K_F, l_e and D are presented in Table 1.

3. Results and discussions

The electrical resistivity of different $V_{82}Pd_{18-x}Fe_x$ alloys has been measured in the temperature range $5 \le T \le 300$ K. From the measured data it is observed that both impurity resistivity ρ_0 (at 10 K) and room temperature resistivity ρ_{300} (at 300 K) increases with increase of Fe content. A linear variation of impurity resistivity with increasing x is shown in Fig. 1. Such linear behaviour indicates a uniform distribution of Fe atoms within the alloys. As the resistivity is the measured of disorder present within the samples, the enhancement of resistivity suggests that disorderness increases with increase of Fe content. The temperature dependence resistivity variation shows a transformation from positive to negative temperature coefficient resistivity (TCR) at $T = T_m$ i.e. we have a minimum resistivity at $T = T_m$. The value of T_m is increased with increase of disorder in the samples and listed in Table 1 for different samples. The anomalous resistivity behaviour at low temperature ($T < T_m$) can be explained by different quantum effects [26–31] and the temperature dependent resistivity corrections can be written as

$$\Delta\rho(T) = \alpha T^{1/2} + \beta T^{p/2} + \gamma \ln T, \tag{1}$$

$$\alpha = -\frac{1.3 e^3 \rho_0^{5/2}}{4\pi^3 \hbar^2}\left[\frac{4}{3} - \frac{3F}{2}\right]\sqrt{\frac{k_B K_F m}{2\hbar}}, \tag{2}$$

where first, second and third terms of Eq. (1) correspond to EEI, WEL and Kondo type scattering respectively. p is an exponent of temperature dependence inelastic scattering time ($\tau_i \sim T^p$), β and γ are two different constants, k_B is the Boltzmann constant, F is a screening factor. To understand the mechanism of anomalous resistivity of the investigated samples, we have plotted resistivity correction $\Delta\rho(T)$ with $\ln T$ and $T^{1/2}$ at zero magnetic fields and shown in Fig. 2(a) and Fig. 2(b) respectively. According to Eq. (1) for dominant Kondo scattering a linear behaviour has been observed in $\Delta\rho(T)$ versus $\ln T$ plot. However Fig. 2(a) shows a nonlinear behaviour of $\Delta\rho(T)$ with $\ln T$ which ruled out the Kondo effect contribution within the samples. On the other hand a straight line variation of $\Delta\rho(T)$ with $T^{1/2}$ has been observed in Fig. 2(b) which suggested the prominent EEI effect. To study the disorder (ρ_0) dependence of resistivity correction as given in Eq. (2), we have plotted in Fig. 2(c) the variation of resistivity slope $\Delta\rho(T)/T^{1/2}$ as a function of $\rho_0^{5/2}$ for $V_{82}Pd_{18-x}Fe_x$ alloys. It is observed from the figure that the resistivity slope increases linearly with $\rho_0^{5/2}$. Hence the observed resistivity correction at low temperature $T < T_m$ finally obeys the prediction of EEI theory $\Delta\rho(T) \sim \rho_0^{5/2} T^{1/2}$. Therefore, we may conclude that the EEI contribution at zero magnetic fields is dominated over WEL contribution at low temperature.

In order to minimize the EEI contribution to magnetoresistivity we have measured the low field ($B \le 0.5T$) transverse magnetoresistivity of different alloys in the temperature range 5–25 K.